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SHUTTLE FLIGHT TEST OF AN ADVANCED GAMMA-RAY DETECTION SYSTEM

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In August of 1983 the Gamma-Ray Advanced Detector (GRAD) Project was assigned to the AFP-675 Program for flight on a future Space Shuttle misson. In order to adapt the experiment to the requirements of AFP-675 we are making a number of changes, both in hardware and software. However, the necessity for such changes is more than affected by an expansion in scope of the experiment made possible by the introduction of a Payload Specialist into the operation.

The principal changes to be made are in the avionics, as GRAD was originally designed for operation through ground-based telemetry. This complete redesigning of our avionics to accomodate operation by a Payload Specialist from the aft flight deck of the Orbiter allows us to take advantage of very recent findings on radiation-induced microprocessor failure in other space shuttle experiments in order to make the GRAD avionics less vulnerable to such latch-ups.

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19. ABSTRACT (continued)

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[illegible] to key words

SUMMARY

In August of 1983 the Gamma-Ray Advanced Detector (GRAD) Project was assigned to the AFP-675 Program for flight on a future Space Shuttle mission. In order to adapt the experiment to the requirements of AFP-675 we are making a number of changes, both in hardware and software. However, the necessity for such changes is more than affected by an expansion in scope of the experiment made possible by the introduction of a Payload Specialist into the operation.

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Table of Contents

1. INTRODUCTION

At the annual Tri-Services Meeting in May of 1983, the GRAD experiment was rated fourth in priority out of the 37 DoD-sponsored space projects presented for review. Subsequently the experiment was assigned a place in the AFP-675 Program. A number of hardware and software changes will be required for operation of the experiment by a Manned Spaceflight Engineer (MSE) rather than by the experimenters through ground-based telemetry. This change in procedure is viewed as an advantage; however, operation of the experiment by a MSE plus the extensive requirements of the AFP-675 Program for documentation, certification, training, support of meetings, mission rehearsals and simulations have greatly increased the complexity of the GRAD Project. Although we have just come into the AFP-675 Program, we find that our already extensive developmental work on GRAD and our previous Shuttle experience have already put us in step with the other AFP-675 experiments.

Having been assigned a specific mission we are now in a position to more clearly define our objectives and the means by which we intend to achieve them. These are outlined in the following section. The present status of GRAD and the major modifications which will be made to the system are then briefly discussed. A list of tasks and the budgets complete the report.

2. OUTLINE OF GRAD MISSION GOALS

I. Technological Goals

A. Determine the effects on bismuth germanate (BGO) and n-type germanium detector materials of exposure to the launch, space and landing environments.

How attained:

1. Determine performance characteristics of GRAD before, during and after the mission. These characteristics include energy resolution, angular resolution, response function and BGO shield efficiency.

2. Monitor housekeeping information (temperatures, voltages, counting rates, dead times)

3. Study crew-removed sample crystals as quickly as they can be removed from returning Orbiter.

4. Do postmission activation measurements on GRAD instrument in OPF-type facility and in ORNL low-background counting laboratory.

B. Test the performance of GRAD as a gamma-ray spectrometer in space and on the ground.

How attained:

1. Accumulate spectra of the ^{239}Pu calibration source plus ambient gamma-ray background.

2. Accumulate spectra with the ^{239}Pu calibration source switched on and switched off to determine how well one can extract a desired signal from the background.

3. Accumulate spectra with the BGO shield switched on and off to determine effectiveness of the shield.

C. Determine radioactivation of detectors and surrounding materials and the nature of the background.

How attained:

1. Study initial activation of Orbiter by turning on GRAD prior to first passage through the South Atlantic Anomaly (SAA).

2. Expose the GRAD to hard particle flux by periodic passage through the SAA and measure the decay of the induced gamma-ray background

in 30-second intervals as the Orbiter passes out of the SAA. (Two sets of 5 upward passages through SAA).

3. Measure spectra with the BGO shield turned off as well as turned on in order to identify the prompt gamma-ray background induced in the nGe and BGO detectors.

4. Measure the decay of postmission activity with intermediate half lives (15m - 24h) by low-background counting of sample crystals flown in the Crystal Sample Package (CSP).

5. Measure the radioactive background with GRAD as soon as the Orbiter is returned to an OPF-type facility.

6. Perform measurements of residual radioactivity in GRAD instrument in the ORNL low-background counting laboratory. (See p. 2).

D. Test the sensitivity of GRAD for the detection and identification of target sources in space.

How attained:

1. Measure the ^{239}Pu calibration source against the Shuttle background.

2. Measure spectra from the galactic center.

3. Measure spectra from targets of opportunity, including solar flares.

E. Explore the usefulness of a gamma-ray spectrometer as a flight crew-controlled instrument for use in the detection and assessment of sources of gamma radiation in space.

How attained:

Provide experiment control and monitoring functions for MSE (see p. 1) through the Command and Monitoring Panel.

II. Scientific Goals

A. Measure the strength of the 0.511-MeV gamma-ray line emitted from the galactic center. Why the strength of this line should fluctuate so dramatically over the span of a few years in such a large astronomical source is not at all understood.

How attained:

Alternate taking spectra of galactic center and preselected background region for a total measuring time of at least 10 hours on each. These spectra wouls best be taken on orbits which do not pass through the SAA. Pointing accuracy should be ±10°.

B. Take solar spectra if a flare should occur during the mission.

3. STATUS OF GRAD

3.1 Delivery and Testing of Major Components

The status of the major hardware and software is summarized in Table 1. Those components of the experiment requiring modification for operation on the AFP-675 pallet are marked with asterisks.

With the exception of a cryostat vacuum problem reported in more detail below, the performance of the n-type germanium (nGe) detector and the bismuth germanate (BGO) shield has been satisfactory in every way. A response function for the integrated spectrometer is shown in Figure 1. Other performance characteristics have been described in an invited paper presented at the International Workshop on BGO at Princeton University (A.C. Rester, et al., submitted to Nuclear Instr. Methods).

Table 1

GRAD Status Report

October 1, 1983

	Design	Construction	Delivery to SAL	Operational Testing	Electrical Testing	Mechanical Testing	Thermal Vacuum Testing	Environmental Testing
A. Flight Ops Hardware								
1. BGO Shield	C	C	C	U	U	C		
2. nGe Detector	C	C	C	U	U			
3. LN Dewar	C	C	C	U		U		
4. Cryogenic Interface*	U							
5. Electronics Cannister*	C	C	C	U		U		
6. Mounting Brackets	U							
7. Nuclear Electronics	C	C	C	U	U			
8. Interface Electronics*	U	U						
9. Command Avionics	U							
10. Calibration Probe*	C							
11. Sample Crystal Container	C	C						
B. Flight Ops Software								
1. Data Acquisition*	C	C	C	U				
2. Data Output*	C							
3. Command and Monitoring Panel								
4. Crew Training Procedures								
C. Ground Ops Hardware								
1. Emulator Computer*	C	C	C	U				
2. Data Handler Computer	C	C	C	U	U			
3. Cryogenics	U							
4. Calibration Hardware	U							
5. Portable Counting Equipment	C							
6. ORNL Hardware	U							
D. Ground Ops Software								
1. Emulator*	U	U	U					
2. Data Handler*	U	U	U					
3. Data Analysis	U	U	U					
4. Monte Carlo.	U	U	U					

Legend:

C = Completed
U = Underway

*These items will require extensive modifications for flight on the USAF P-675 pallet.

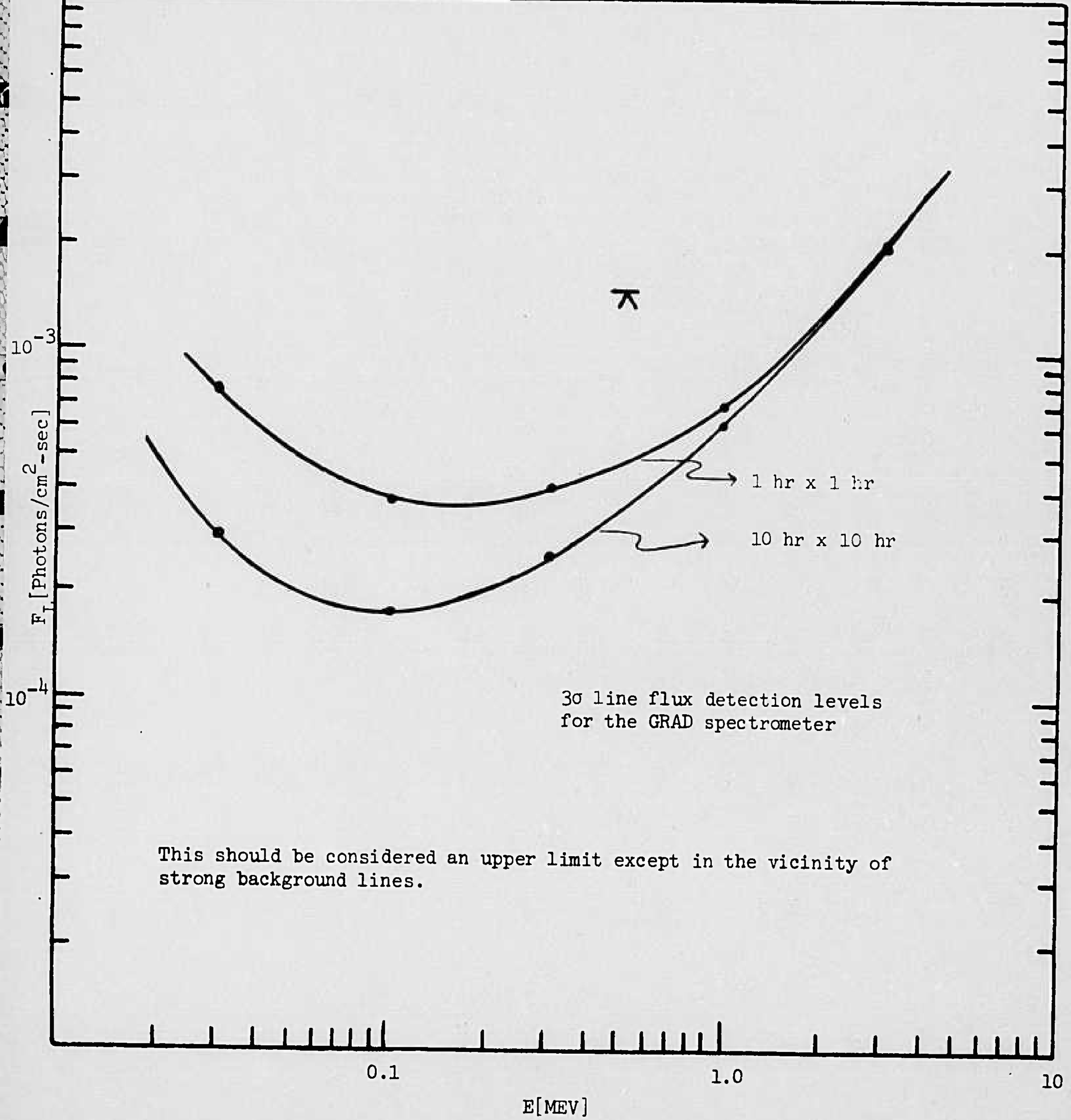

10^{-3}
10^{-4}
F_I [Photons/cm^2-sec]
1 hr x 1 hr
10 hr x 10 hr
3σ line flux detection levels
for the GRAD spectrometer
This should be considered an upper limit except in the vicinity of strong background lines.
0.1
1.0
10
E[MEV]

Figure 1

3.2 Modifications Required on Flight Electronics

The present GRAD Flight Electronics Package was designed for interfacing with the OSS-1 ground-linked telemetry system or with a self-contained recorder system for possible operation with reduced mission objectives. These electronics were delivered to SAL in August 1983 for bench testing and subsequently returned to Cedar Rapids for second-pass modifications. Interfacing GRAD with AFP-675 has required extensive changes in the controller microcomputer but not the nuclear electronics. In the new configuration the experiment will be controlled from a Command and Monitoring Panel on the aft flight deck of the Orbiter by an MSE. The GRAD microcomputer has been replaced by a more versatile computer having the capability to handle the more complex operations required for control by a flight crew member. As a result of an engineering study comparing the Rockwell 6502, INTEL 8086 and Motorola 68000 microprocessors, we have selected the 68000 microprocessor and will build at the modular, rather than the chip level.

The greater versatility of the redesigned controller will also permit us to program a "fast" data acquisition mode for better observation of targets of opportunity.

3.3 Loss of Vacuum in the nGe Detector Cryostat

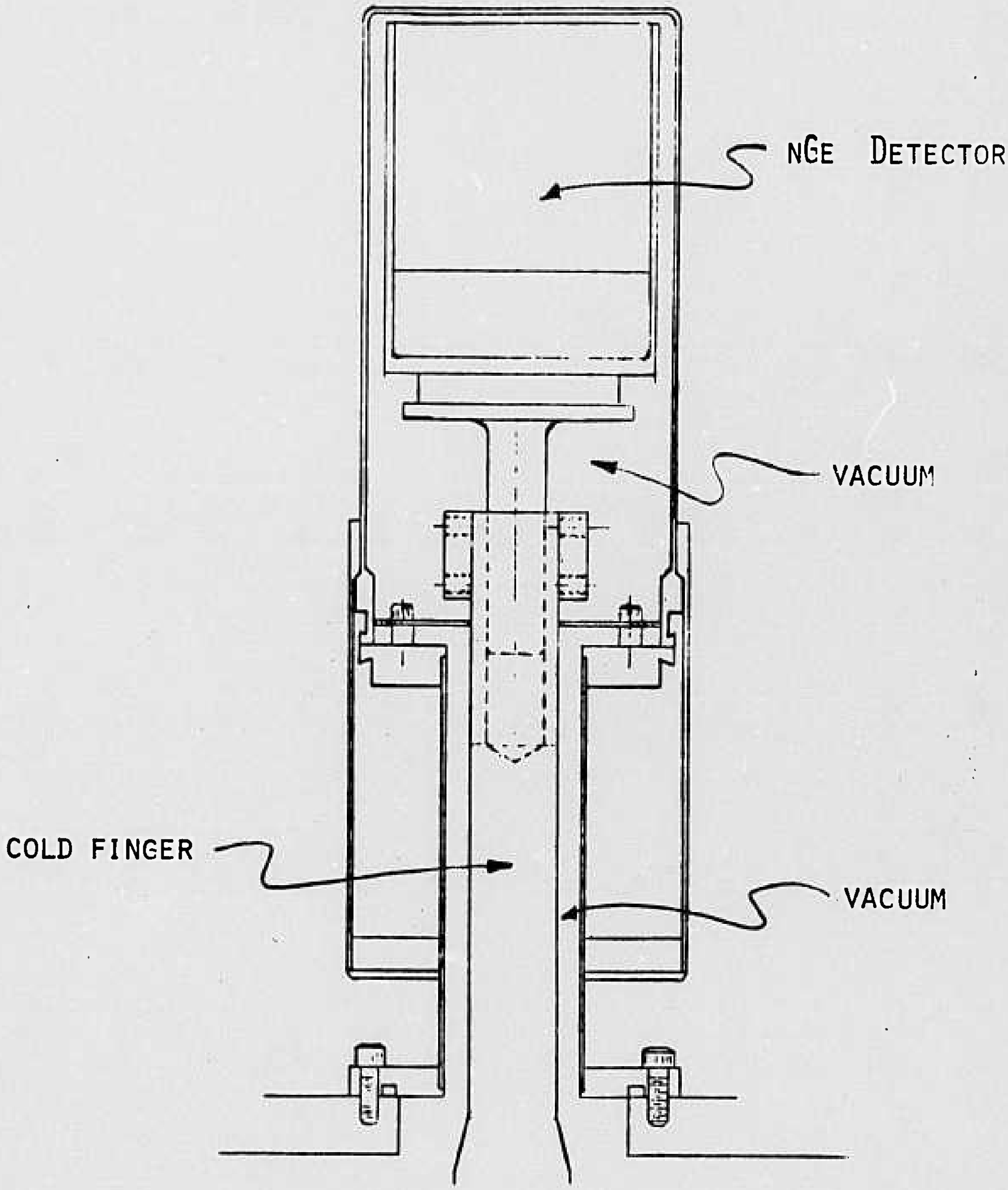
On September 7, 1983 a failure of the vacuum in the germanium detector cryostat occurred. Prior to this failure the detector had been kept at room temperature for about a month while a new check valve was being installed in the nitrogen vent tube. The loss of vacuum appears to have been due to outgassing of some material within the cryostat over the month during which it was kept at room temperature.

A vacuum failure in the cryostat is a performance but not a safety problem. (As one can see in Figure 2, the cryostat is that part of the nGe detector housing that fits into the top of the liquid nitrogen dewar.) It causes a substantial, but not catastrophic increase in the liquid nitrogen boiloff rate and the detector becomes inoperable due to contamination of its surfaces. Neither effect would occur in orbit, as the entire system would be under vacuum.

The effect of this vacuum failure on the GRAD project is not expected to be significant; however, such a failure requiring servicing inside the cryostat within 20 days of launch would be a very serious matter. To cover this single-point failure mode, we are therefore budgeting for a backup nGe detector. Other components of the GRAD hardware are already covered. Modular construction of the electronics will permit board-by-board replacement without removal of the electronics unit from the pallet.

Under the assumption that it is not required for substitution of the Flight unit, the backup nGe detector will be used for the accumulation of high-resolution spectra in the postflight measurements at the landing site.

Figure 2. Detail of GRAD nGe Detector Cryostat



* See Figure 2A for updated detail.

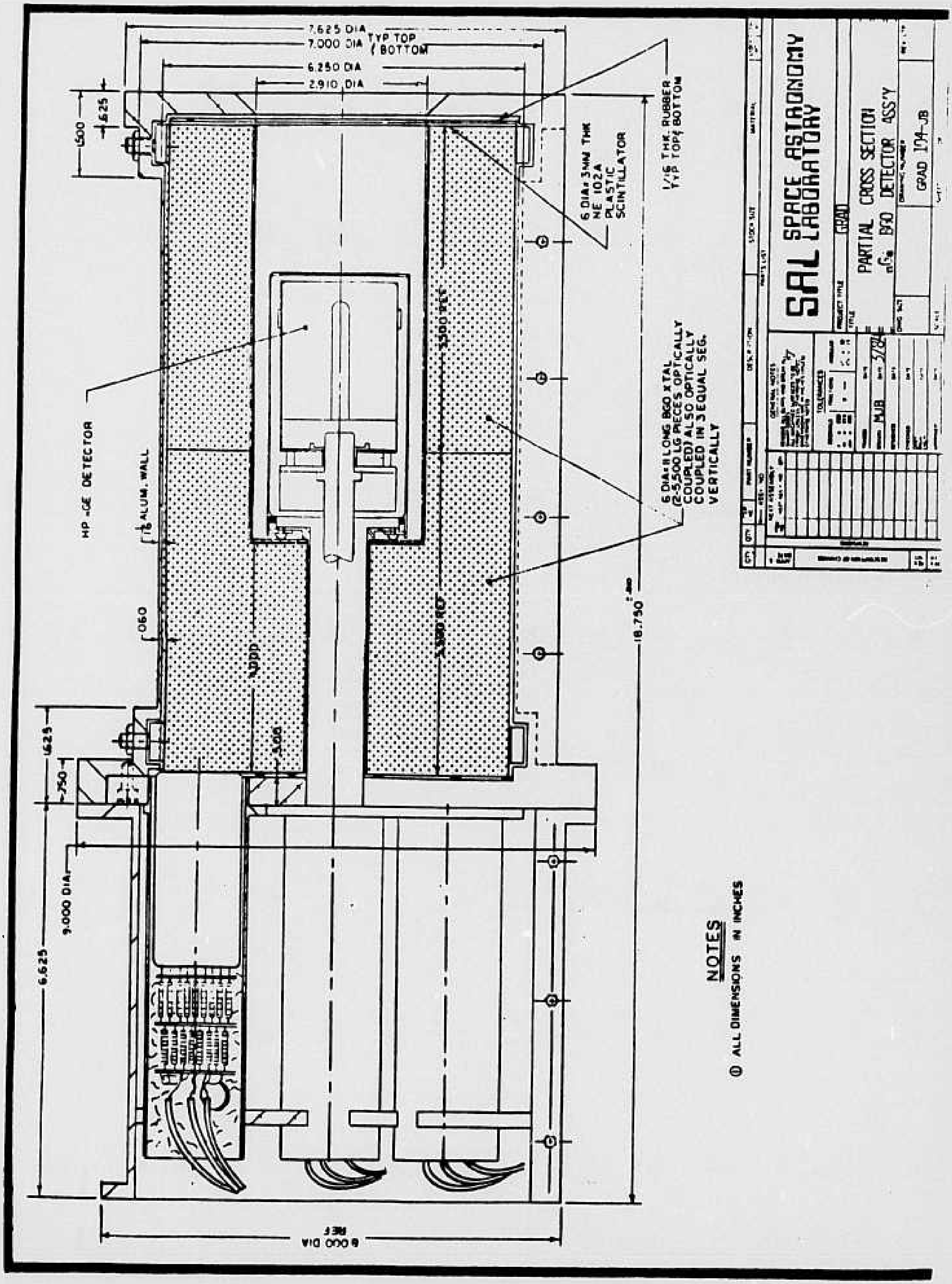

7.625 DIA
7.000 DIA TYP TOP & BOTTOM
6.250 DIA
2.910 DIA
.500
.625
6 DIA x 3MM THK NE 102A PLASTIC SCINTILLATOR
1/16 THK. RUBBER TYP TOP & BOTTOM
HP-GE DETECTOR
1/8 ALUM. WALL
.060
6 DIA x 11 LONG BGO XTAL (2-5.500 LG PIECES OPTICALLY COUPLED) ALSO OPTICALLY COUPLED IN 3 EQUAL SEG. VERTICALLY
18.750
.750
.625
9.000 DIA
6.625
8.000 DIA REF
NOTES
1 ALL DIMENSIONS IN INCHES
SAL SPACE ASTRONOMY LABORATORY
GRAD
PARTIAL CROSS SECTION
BGO DETECTOR ASS'Y
MJB
GRAD 104-JB

Figure 2A

4.0 GRAD PROJECT ORGANIZATION

GRAD PROJECT ORGANIZATION

For purposes of planning and management the GRAD project is organized into eight project elements:

1.0 GRAD Project Administration

2.0 GRAD Project Operations

3.0 GRAD Ground Support Equipment and Testing Facilities

4.0 GRAD Flight Hardware and Software

5.0 GRAD Calibrations

6.0 GRAD-to-ESS and -STS Integration Support

7.0 GRAD Crystal Sample Package

8.0 GRAD Data Reduction and Analysis

GRAD TASKS PLAN

TASK ITEM	COMPLETION DATE DEADLINE
1.0 GRAD Project Administration	
1.1 support technical interchange meetings	as needed
1.2 support experimenter working group meetings	as needed
1.3 support critical design review	4Q2
1.4 support scientific interchanges	as needed
1.5 support professional meetings	as needed
1.6 support DARPA meetings	as needed
1.7 prepare semi-annual reports	as required by AFOSR
1.8 support SAL planning meetings	as needed
1.9 coordinate activities of GRAD personnel	as needed

2.0	GRAD Project Operations	
2.1	provide input to Lockheed for ICD preparation	as needed
2.2	provide input to Lockheed for FORD preparation	as needed
2.3	provide input to Lockheed for GORD preparation	as needed
2.4	crew training	
2.4.1	write GRAD training manuals	TBD
2.4.2	provide scientific and technical training at SAL for flight crew candidates	TBD
2.5	support operations meetings	
2.5.1	ground operation reviews	4Q2
2.5.2	flight operation reviews	
2.5.3	technical interchange meetings at launch and landing sites	***dates classified
2.6	support POCC training for experimenters	***dates classified
2.7	support CMP simulator training for PI and Project Manager	
2.8	support flight rehearsals and simulations	TBD
2.9	support mission operations	***dates classified
3.0	GRAD Ground Support Equipment and Testing Facilities	
3.1	develop electronic test stand	
3.1.1	design and construct test stand	completed
3.1.2	formulate design modifications	4Q1
3.2.3	complete test chamber modifications	4Q2
3.2	develop component level vacuum test chamber	
3.2.1	design and construct test chamber	completed
3.2.2	formulate design modifications	4Q1
3.2.3	complete test chamber modifications	4Q2
3.3	develop ground support equipment for the GRAD	
3.3.1	design ground support equipment	completed
3.3.2	formulate design modifications for GSE	4Q1
3.3.3	construct and assemble GSE	4Q4
3.3.4	test GSE hardware	4Q4
3.3.5	design GSE and ground test software	4Q2
3.3.6	complete and test GSE software	4Q4

4.0 GRAD Flight Hardware and Software

4.1 design and construct dewar detector assembly

4.1.1	design and construct germanium detector assembly	completed
4.1.2	design and construct liquid nitrogen dewar	completed
4.1.3	design and construct bismuth germanate annulus	completed
4.1.4	design decay vetoed calibration probe (DVCP)	4Q1
4.1.5	construct and test DVCP	4Q2
4.1.6	design cryo service panel	4Q1
4.1.7	construct and test cryo service panel	4Q2
4.1.8	design electrical I/F service panel	4Q2
4.1.9	construct and test electrical I/F panel	4Q3
4.1.10	final assembly of the dewar-detector assembly	4Q4
4.1.11	construct (with ORTEC) backup germanium detector	5Q1

4.2 design and construct electronic support package

4.2.1	design and construct data acquisition electronics	completed
4.2.2	modify design of micro processor controller	4Q1
4.2.3	construct micro processor controller	4Q3
4.2.4	design electronic support package housing	4Q2
4.2.5	construct electronic support package housing	4Q3
4.2.6	assemble electronic support package	4Q4
4.2.7	design and construct wiring harness	4Q4
4.2.8	design controller software	4Q2
4.2.9	complete and test controller software	4Q3

4.3 design and construct (with Lockheed) the GRAD-SV interface

4.3.1	determine interface requirements	4Q1
4.3.2	input to Lockheed preliminary specifications	4Q1
4.3.3	input to Lockheed final specifications	4Q2

4.4 design, construct and deliver to Lockheed a mass model

4.4.1	input to Lockheed initial GRAD characteristics	completed
4.4.2	design and construct mass model	4Q1
4.4.3	deliver mass model to Lockheed	4Q2

4.5 design and construct (with Lockheed) mechanical and thermal models

4.5.1	initial mechanical model input to Lockheed	completed
4.5.2	initial thermal model input to Lockheed	completed
4.5.3	input intermediate mechanical parameters	as required
4.5.4	input intermediate thermal parameters	as required

4.5.5	input test results and final techanical input to Lockheed	5Q1
4.5.6	input final thermal characteristics to Lockheed	5Q1

4.6 GRAD hardware-software testing and burn-in

4.6.1	subassembly functional tests	4Q3
4.6.2	subassembly thermal vacuum test	4Q3
4.6.3	subassembly vibration tests	4Q3
4.6.4	subassembly load tests	4Q3
4.6.5	subassembly burn-ins	4Q4
4.6.6	GRAD dewar certification	4Q3
4.6.7	GRAD electronics package housing certification	4Q3
4.6.8	GRAD hardware-software functional tests	4Q4
4.6.9	GRAD thermal vacuum tests	4Q4
4.6.10	GRAD vibration tests	4Q4
4.6.11	GRAD load tests	4Q4
4.6.12	final GRAD burn-in	4Q4

5.0 GRAD Calibration

5.1 preliminary calibrations

5.1.1	calibration of detector subassemblies	completed
5.1.2	calibration of PAD-ADC-detector subassembly	4Q3

5.2 GRAD calibrations at SAL with radioactive sources

5.2.1	GRAD energy and efficiency calibrations	5Q1
5.2.2	GRAD compton suppression efficiency calibrations	5Q1
5.2.3	GRAD directionality calibrations	5Q1
5.2.4	GRAD thermal correction coefficients	5Q1

5.3 GRAD calibrations at UF accelerator

5.3.1	design and construction of GRAD mounting	4Q4
5.3.2	GRAD energy and efficiency calibrations	4Q4
5.3.3	GRAD directionality calibrations	4Q4

6.0 GRAD-to-ESS and -STS Integration Support

6.1	GRAD integration at Lockheed	***dates classified
6.2	perform post-integration GRAD tests	***dates classified
6.3	attend and support Lockheed tests	***dates classified
6.4	S/V integration at launch site	***dates classified

7.0	GRAD Crystal Sample Packages	
7.1	design and construct crystal sample packages	
7.1.1	flight deck package	4Q2
7.1.2	cargo bay package	completed
7.2	input to Lockheed interface design constraints	4Q1
7.3	design and construct sample package mounting bracket	4Q1
7.4	preparation of counting chambers	
7.4.1	primary facility at ORNL	4Q2
7.4.2	portable facility for landing site	4Q2
7.5	background and calibration measurement	
7.5.1	ORNL measurements	5Q1
7.5.2	landing site measurements	***dates classified
7.6	post-flight activity measurements	
7.6.1	measure sample crystal activation at landing site	***dates classified
7.6.2	measure GRAD/Orbiter activation before de-integration	***dates classified
7.6.3	measure long term activities at ORNL	***dates classified
7.7	dosimetry measurements	
7.7.1	measurements at radiation dosimetry lab, NASA-Johnson Space Center	***dates classified
8.0	GRAD Data Reduction and Analysis	
8.1	GRAD calibration data	
8.1.1	GRAD energy and efficiency data	5Q1
8.1.2	GRAD compton-suppression efficiency data	5Q1
8.1.3	GRAD directionality data	5Q1
8.1.4	GRAD thermal correction coefficients data	5Q1
8.2	crystal background and calibration measurements	5Q1
8.3	preflight crystal activity measurements	5Q2,
8.4	postflight crystal activity measurements	***dates classified ***dates classified
8.5	dosimetry measurements	***dates classified
8.6	flight data	***dates classified

8.6.1 experimental gamma-ray spectra
8.6.2 calibration spectra
8.6.3 housekeeping data

8.7 reporting

8.7.1	professional meetings	as required
8.7.2	scientific journals	as required
8.7.3	agency reviews	as required